Assessing Aircraft Icing Environments

FAA In-flight Icing/Ground De-icing International Conference

Stewart G. Cober[1], George A. Isaac[1], Alexei V. Korolev[2] and J. Walter Strapp[1]

1. Cloud Physics Research Division
2. SkyTech Research Inc.

Meteorological Service of Canada
Service meteórólogique du Canada

Aim

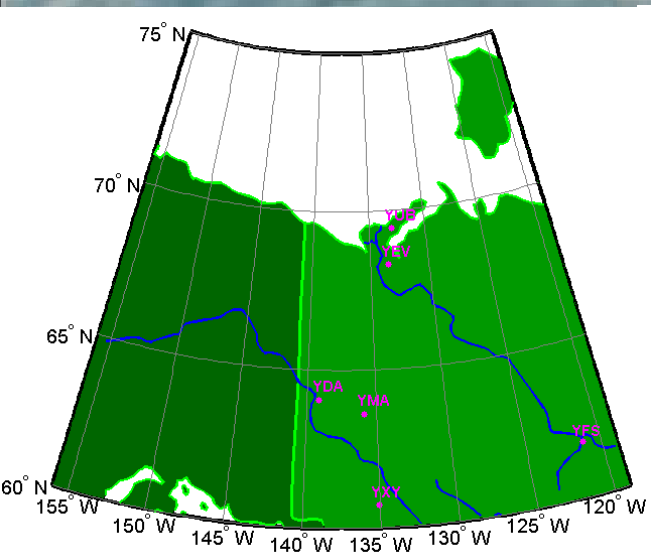
To provide guidance on how to interpret some instruments that, for research and certification purposes, may be used for characterizing icing environments.

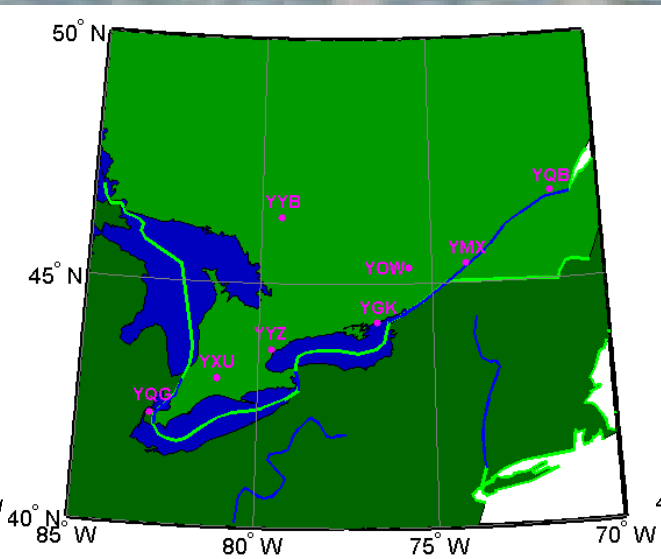
Outline

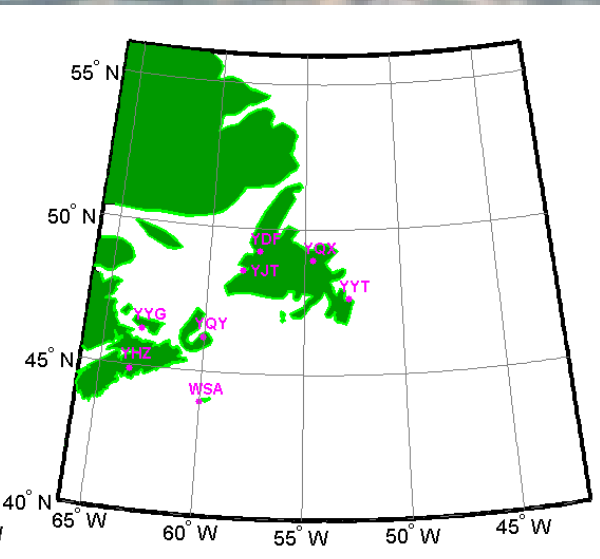
- Background
- Hot Wire LWC Measurements
- Rosemount Icing Detector Measurements
- FSSP Droplet Measurements
- 2D Hydrometeor Measurements
- Identification of Cloud Phase
- Conclusions

Field Projects Used For This Analysis

• CFDE I	27 Feb 1995 - 24 Mar 1995	48 Hours
• CFDE III	10 Dec 1997 - 18 Feb 1998	106 Hours
• FIRE.ACE	01 Apr 1998 - 29 Apr 1998	74 Hours
• AIRS	02 Dec 1999 -19 Feb 2000	95 Hours
• Total	81 Flights	323 Hours





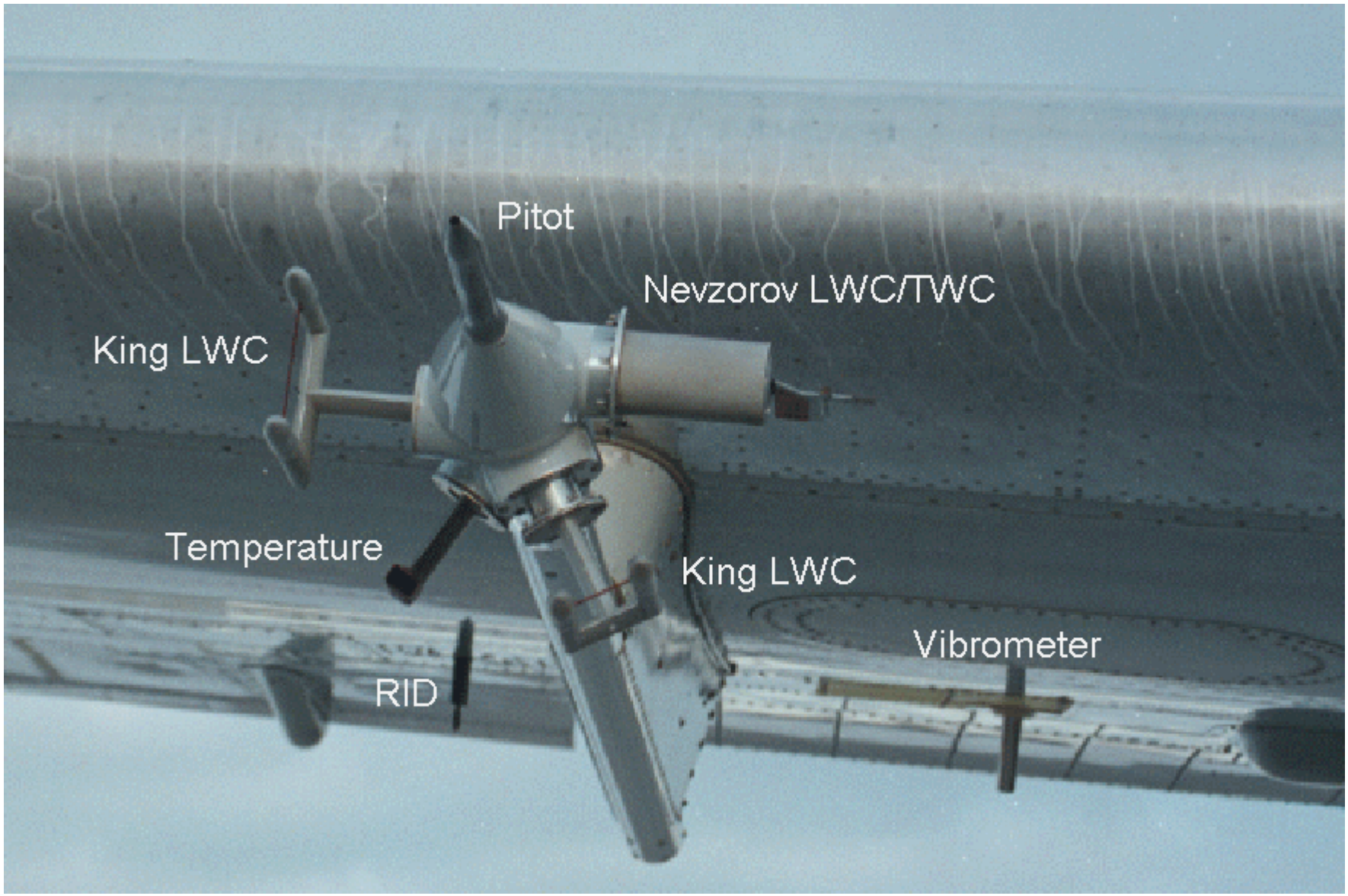


NRC Convair-580

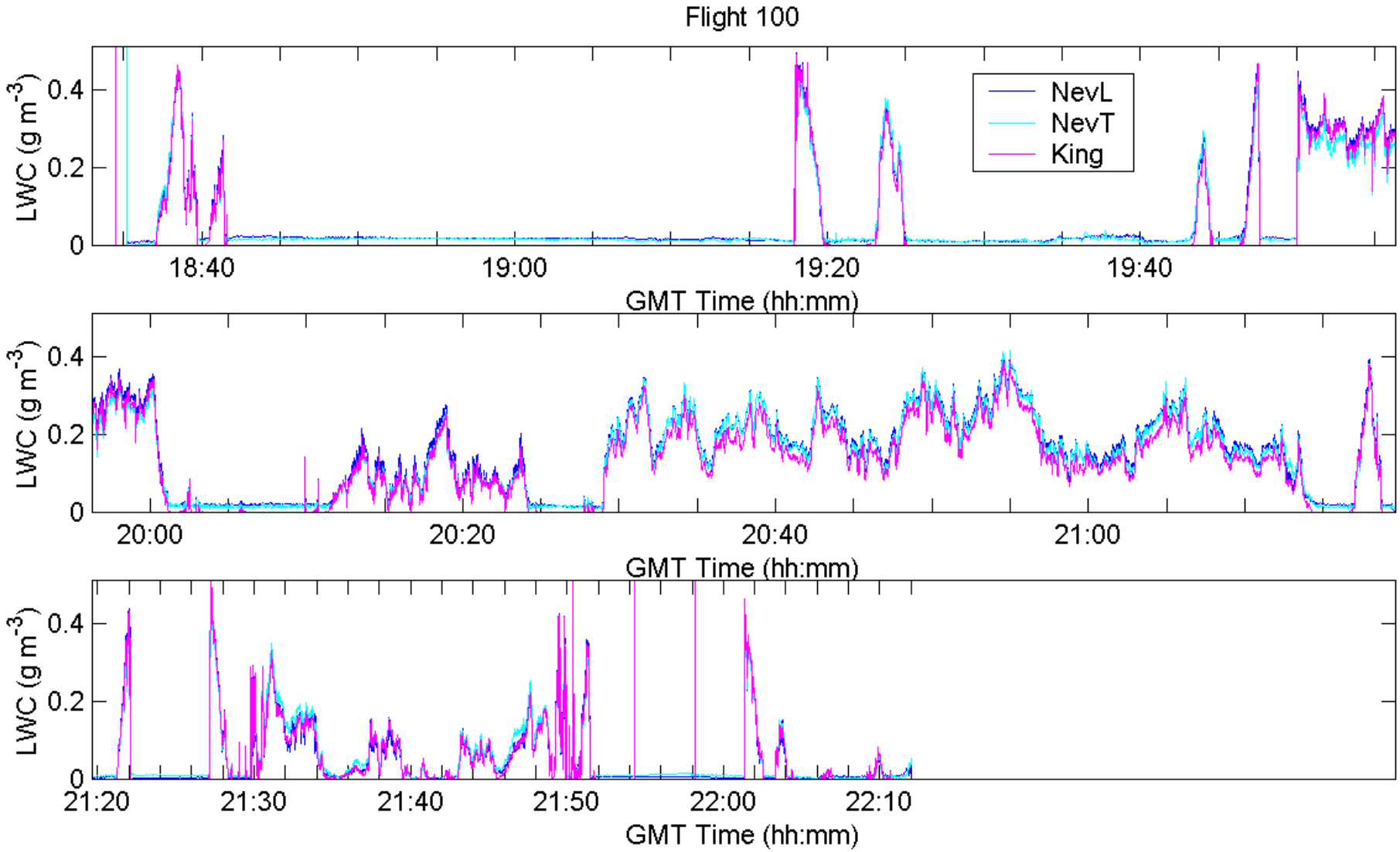
Instrument	Variable
• Rosemount temperature sensor (x2)	Temperature
• Reverse flow temperature sensor	Temperature
• Cambridge dew point hygrometer	Dew Point
• Pitot tube (x3)	Air speed, pressure
• Rosemount-858 probe	Air speed, pressure
• PMS King LWC probe (x2)	Liquid water content
• Nevzorov LWC probe	Liquid water content
• Nevzorov TWC probe	Total water content
• PMS FSSP 100 3-45 microns	Droplet concentration/size
• PMS FSSP 100 5-95 microns	Droplet concentration/size
• PMS 2D-C Mono 25-800 microns	Hydrometeor conc./size
• PMS 2D-C Grey 25-1600 microns	Hydrometeor conc./size
• PMS 2D-P Mono 200-6400 microns	Hydrometeor conc./size
• Rosemount Icing Detector	Icing accumulation rate

Hot Wire LWC Measurements

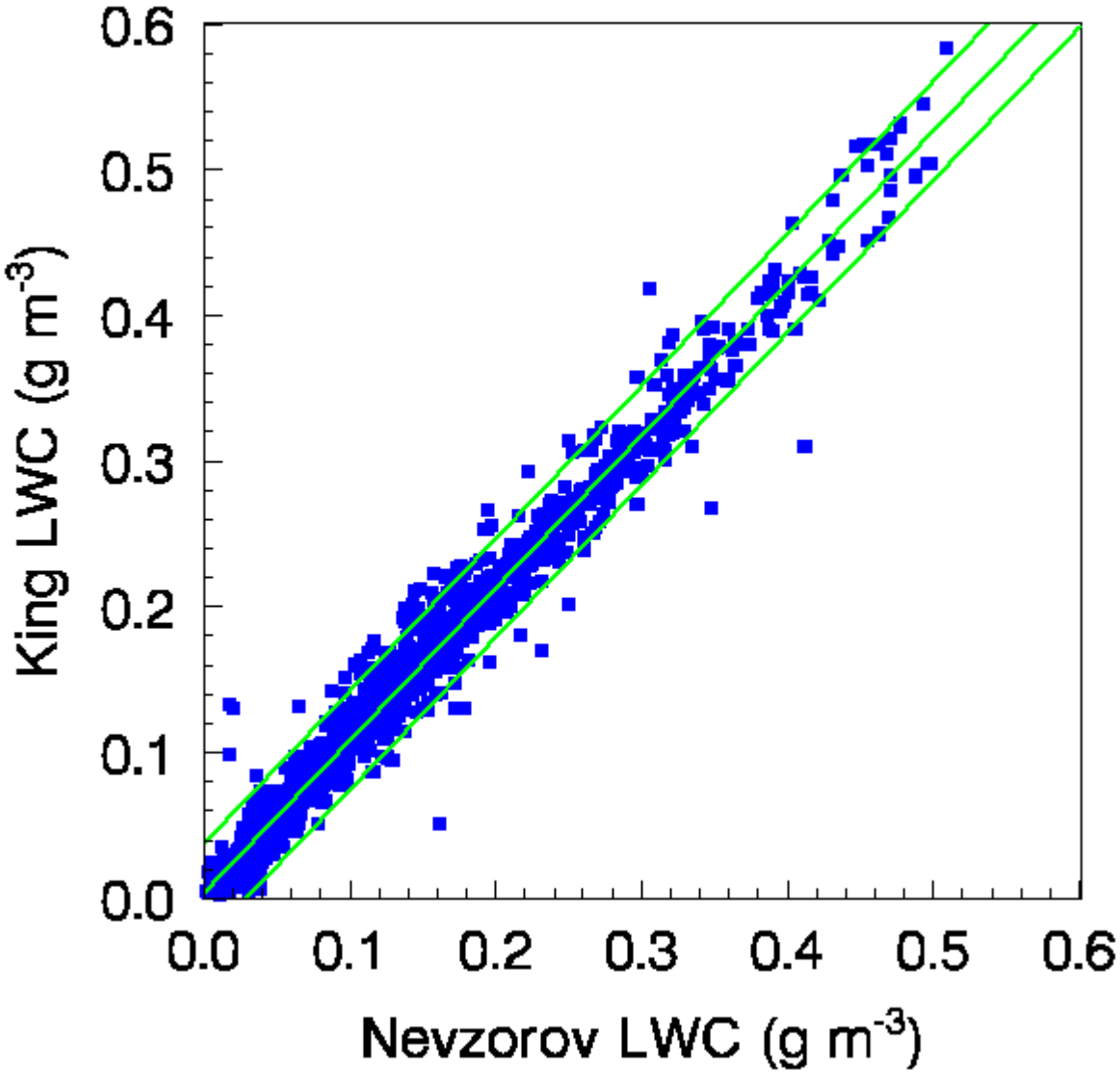
Convair-580 LWC Boom



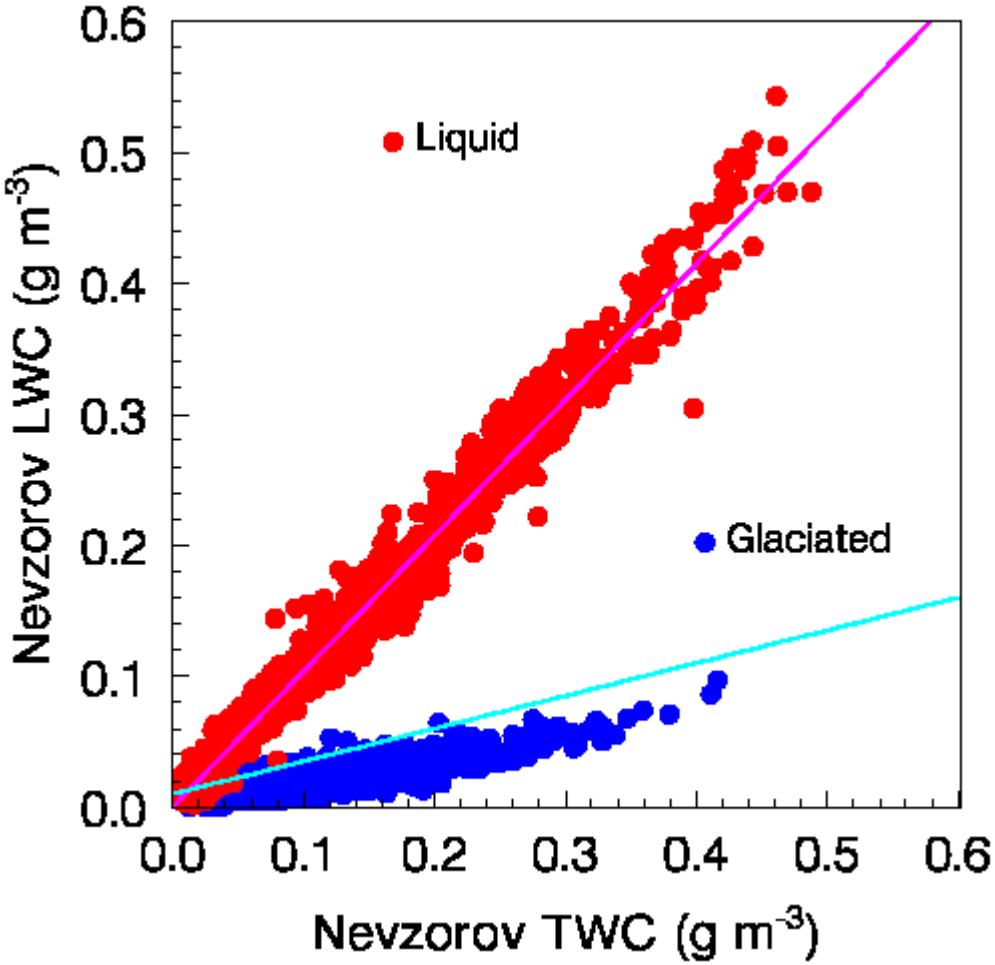
Time History of LWC



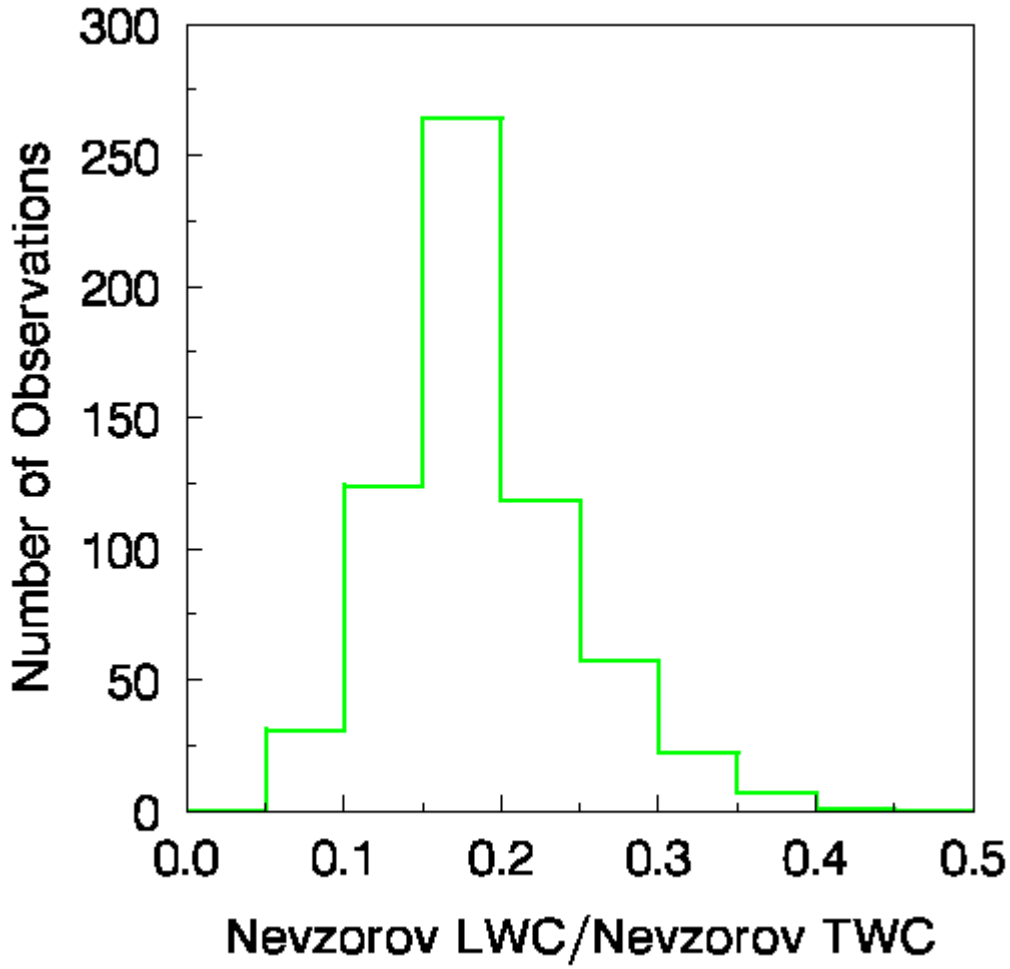
Hot Wire LWC Comparison



LWC Probe Response to Ice

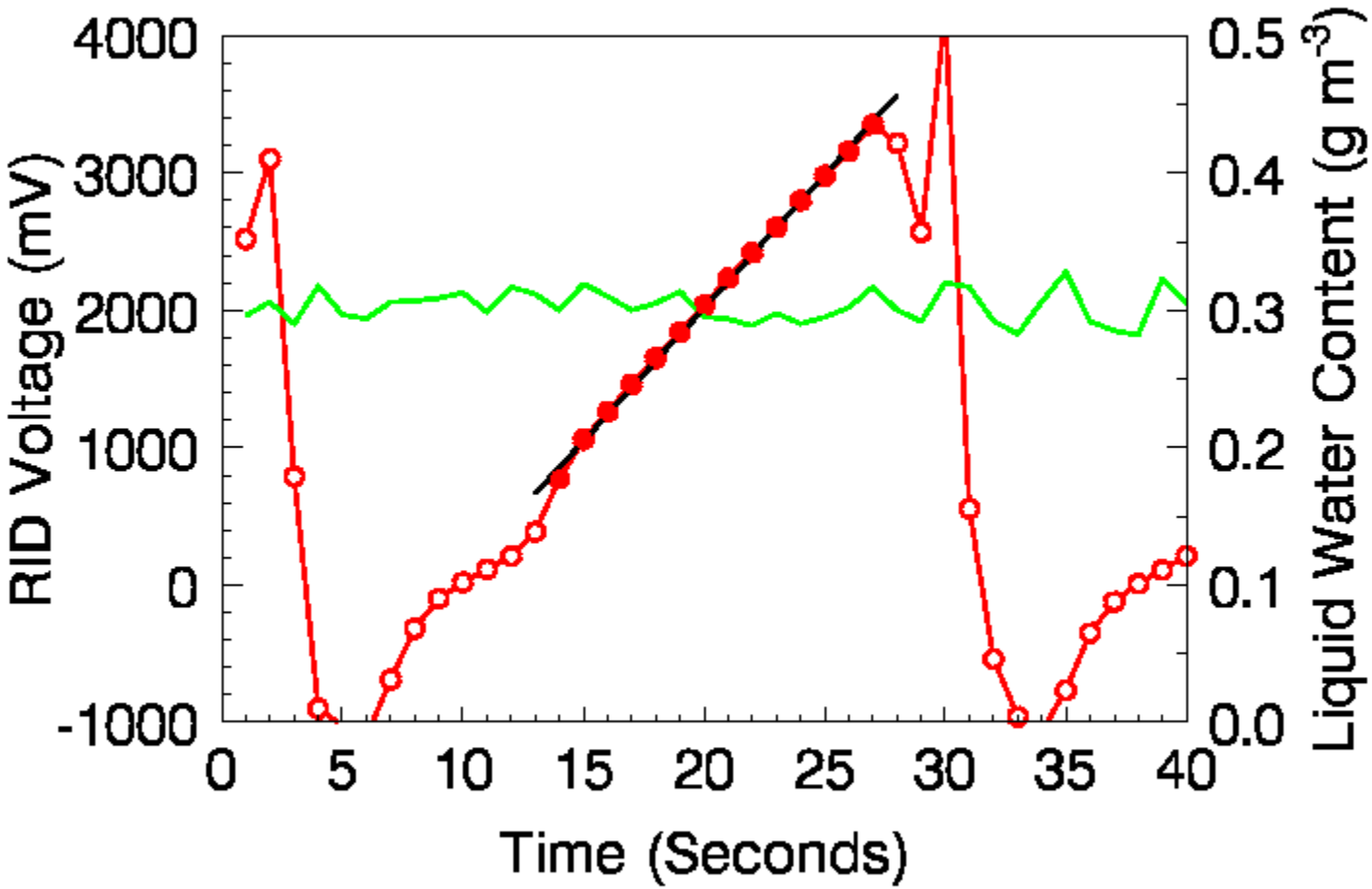


LWC Probe Fractional Response to Ice

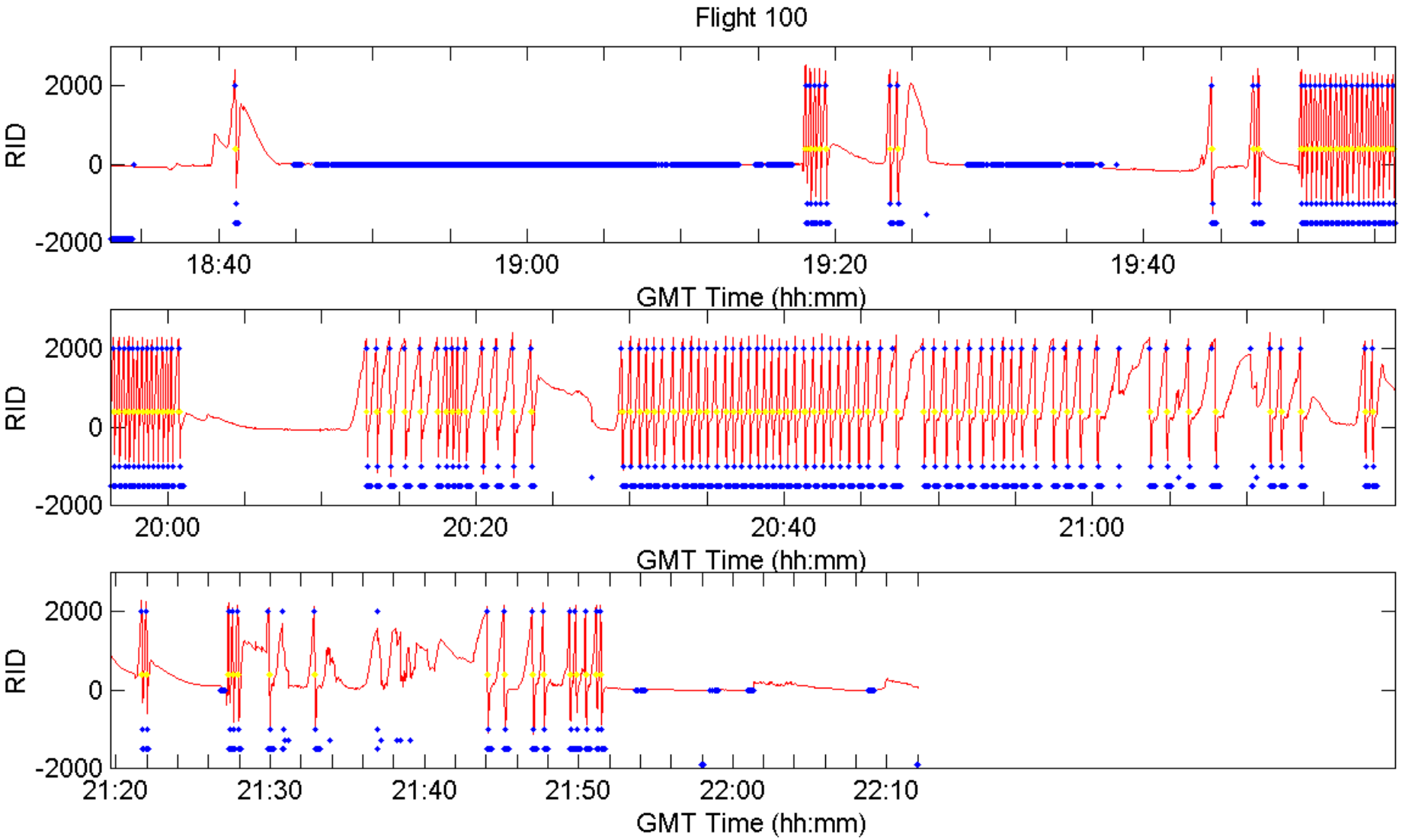


Rosemount Icing Detector Measurements

Example of a RID Cycle



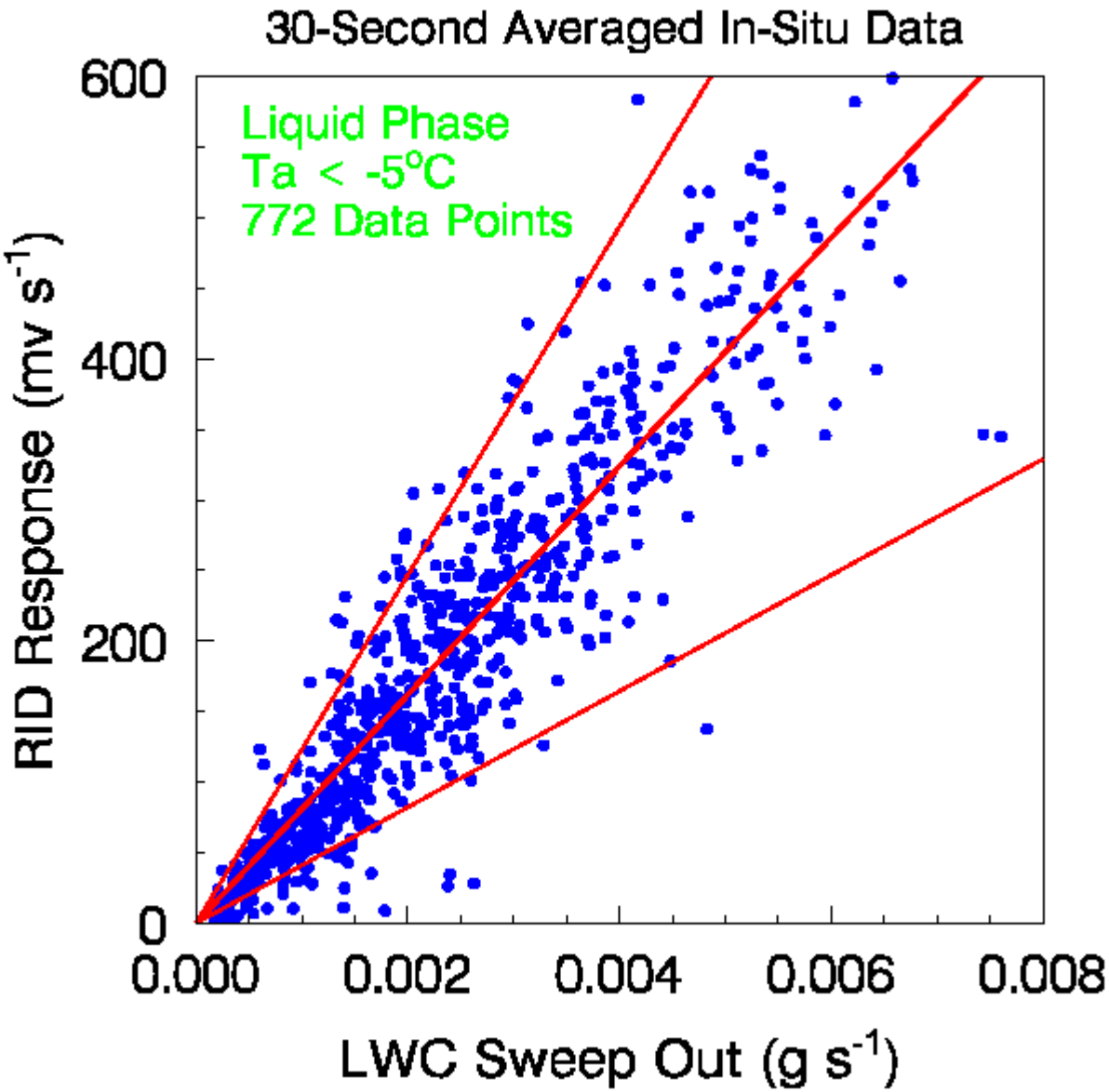
Time History of RID Signal



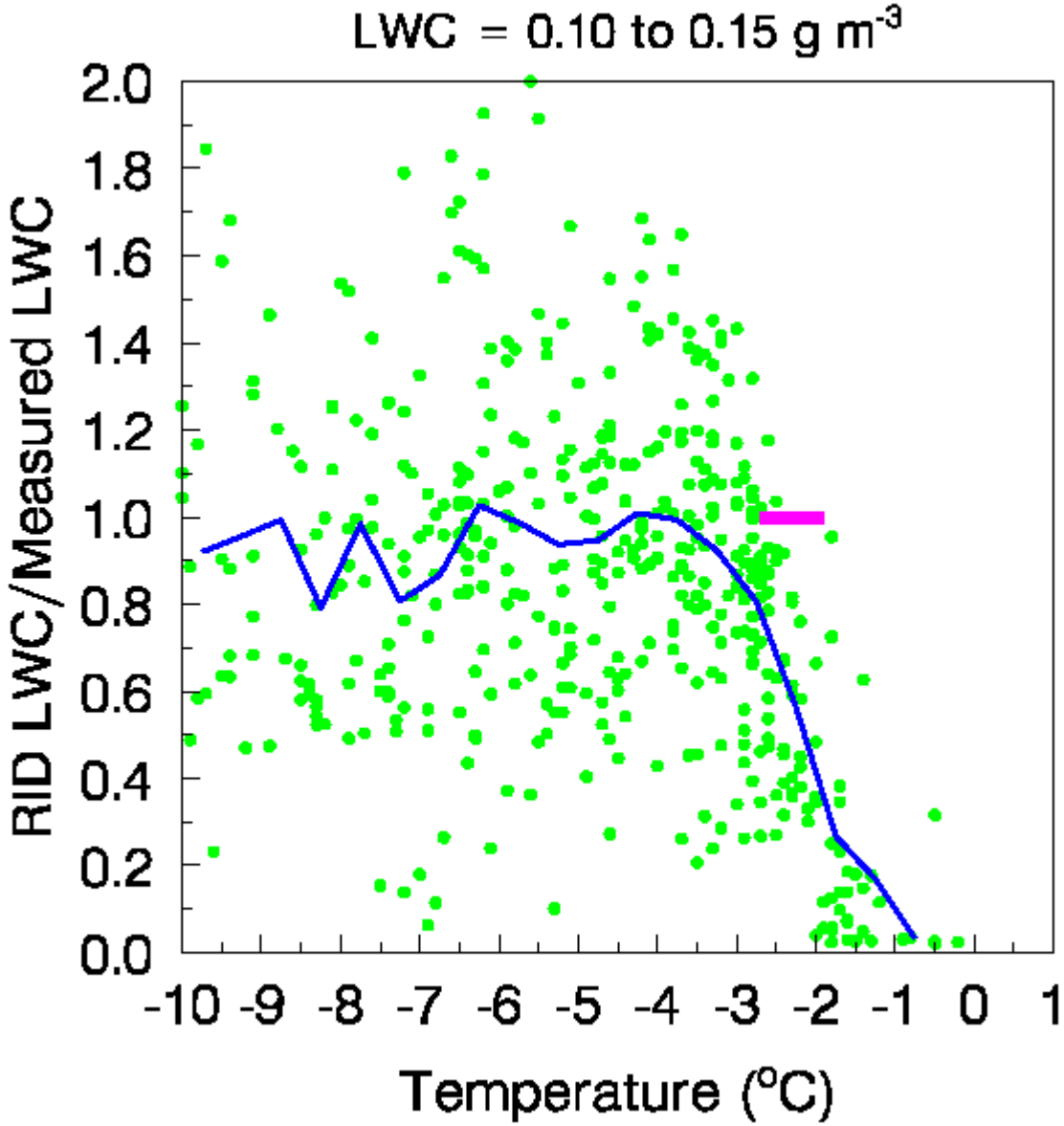
$$\frac{dV}{dt} = k\,E\,A\,V_e\,LWC = k\,\frac{dM}{dt}$$

- dV/dt is the rate of change of voltage (mV s^{-1})
- k is the slope
- *E* is the drop collision-collection efficiency
- A is the area of sweep out for the RID (m^2)
- V_e is the aircraft/RID velocity (m s^{-1})
- LWC is the cloud liquid water content (g m^{-3})
- dM/dt is the mass sweep out with time (g s^{-1})

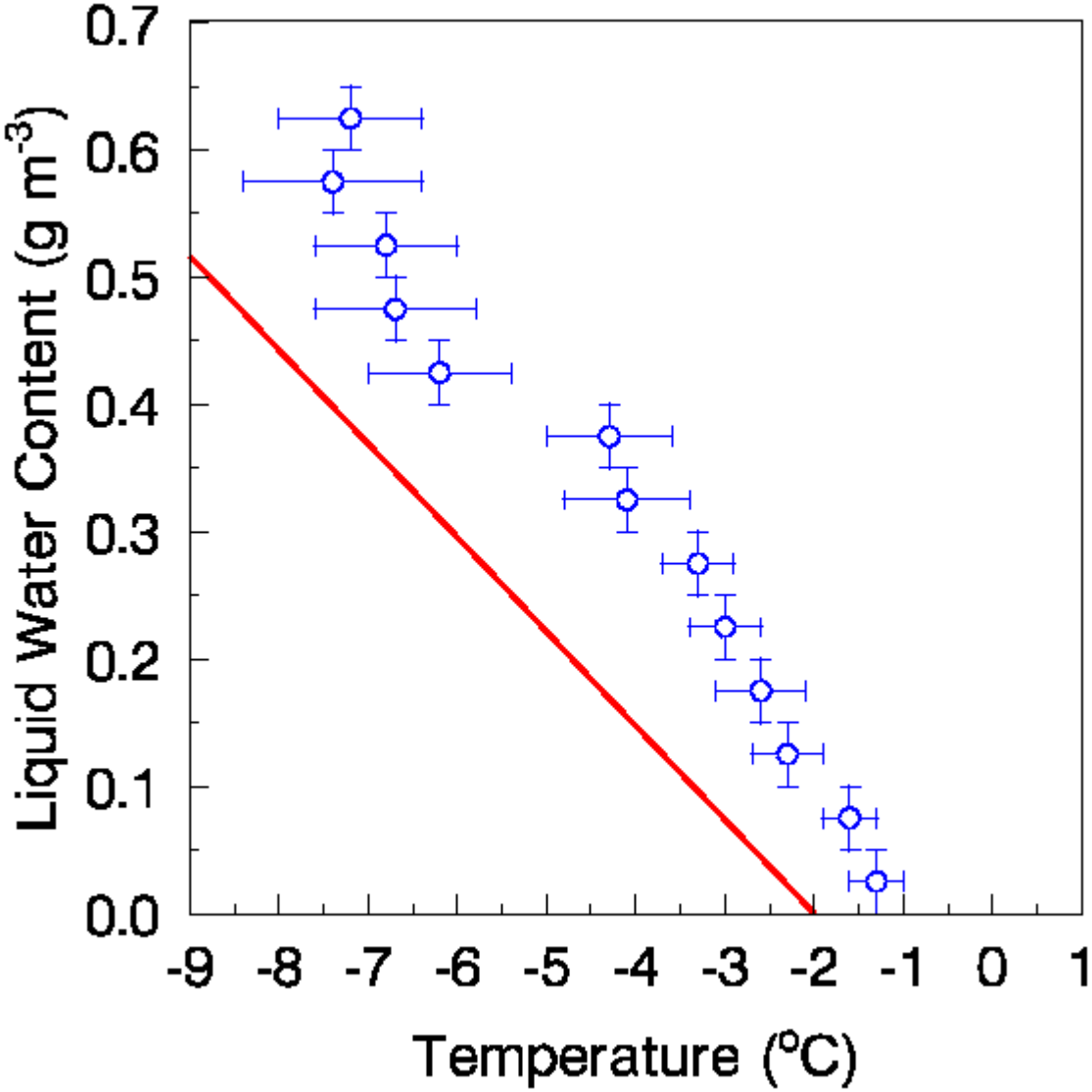
Correlation with LWC



Determination of Non-Linear Response

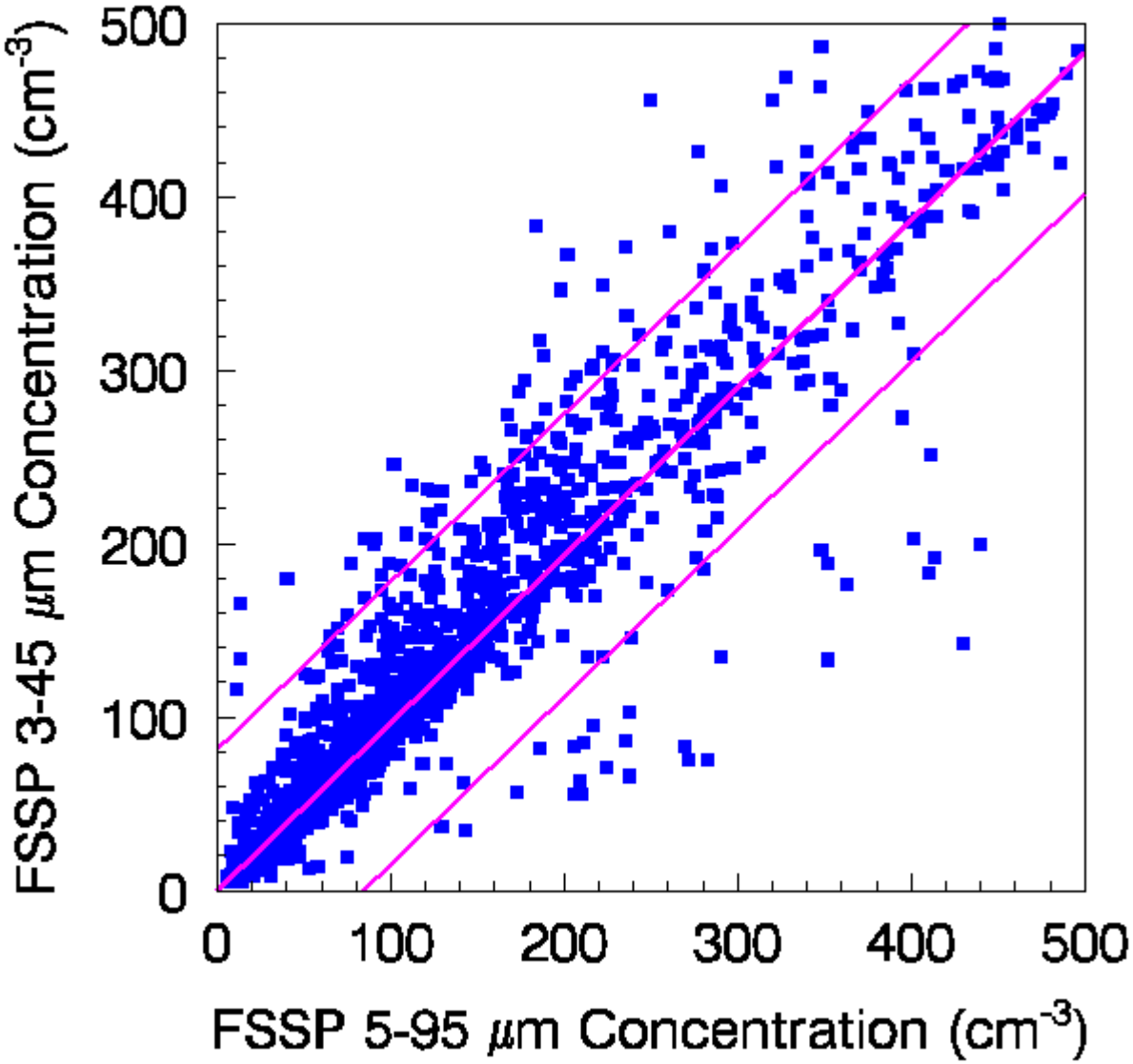


Ludlam Limit Estimation

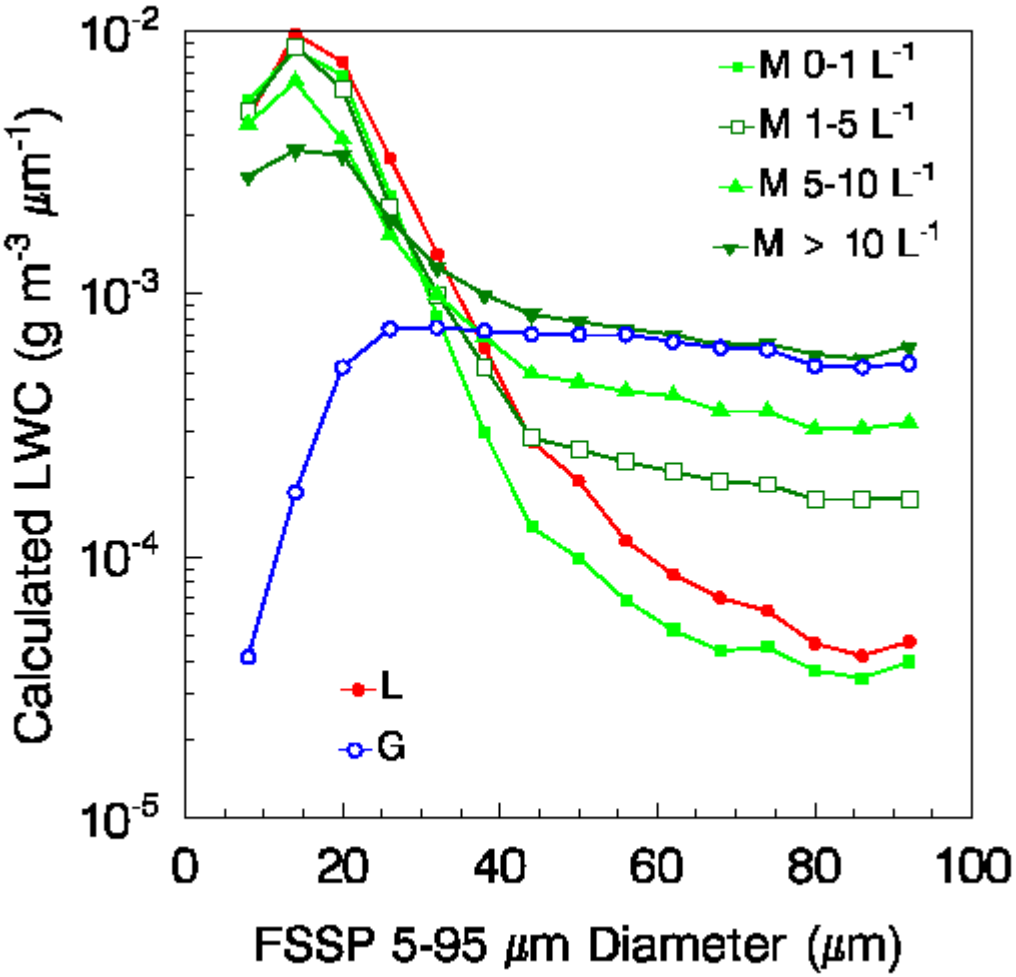



FSSP Droplet Measurements

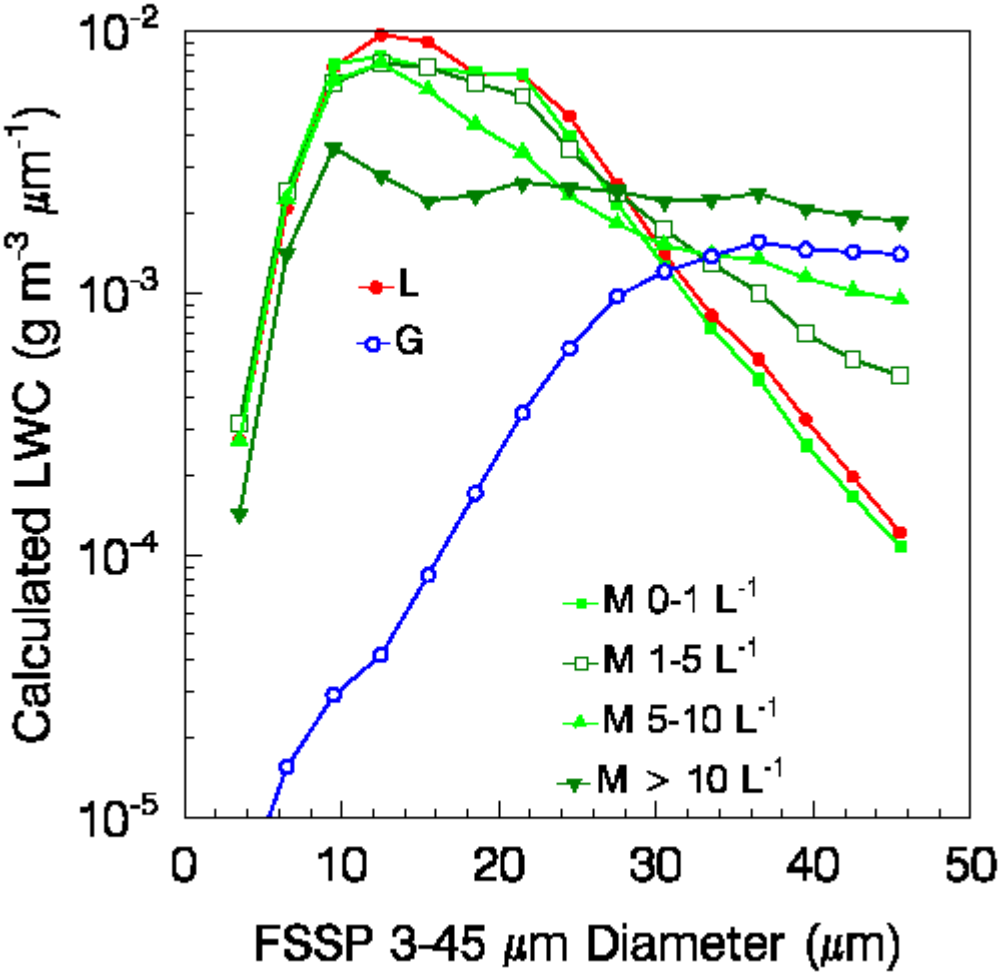
FSSP Concentration Comparison



FSSP 5-95 μm Response to Ice

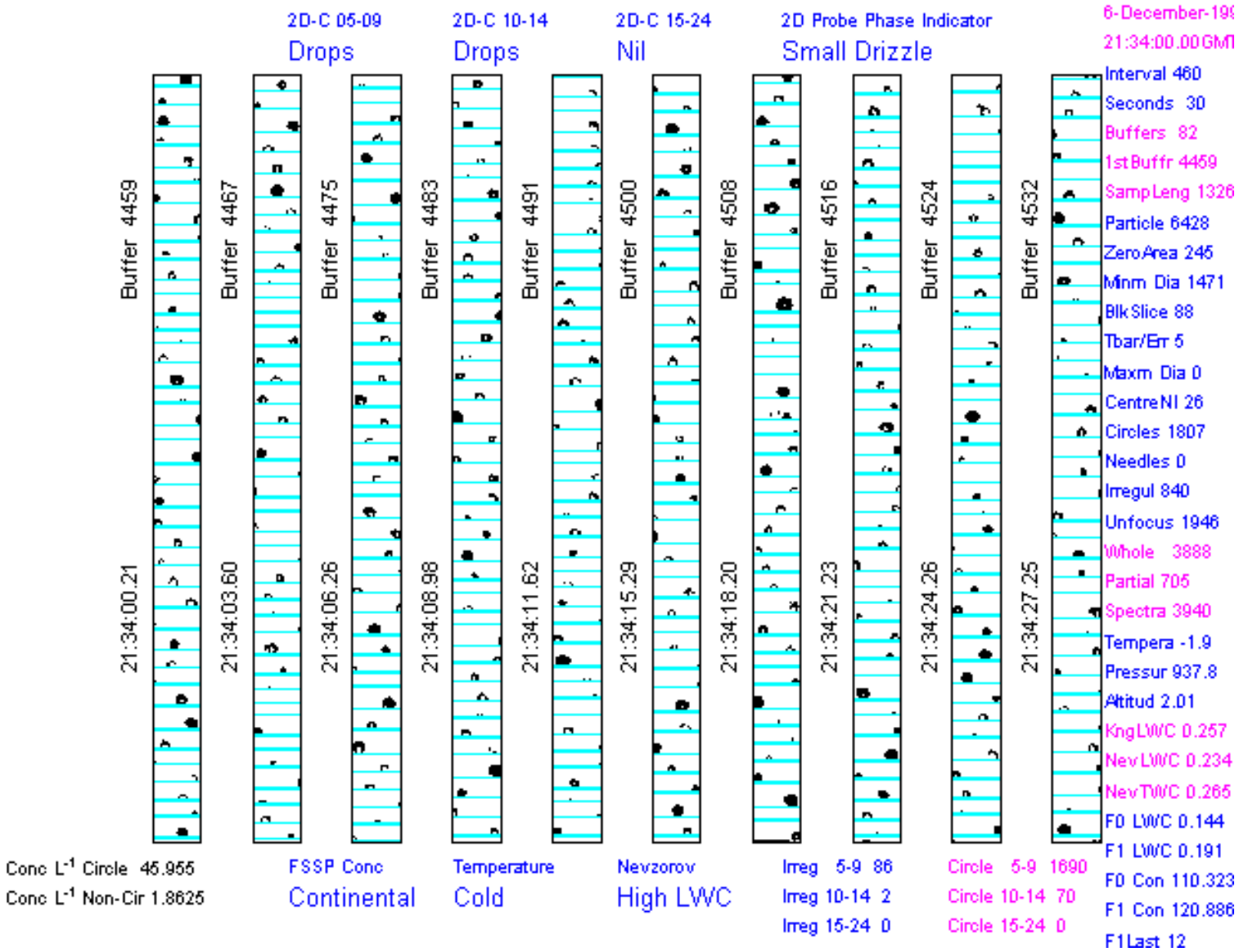


FSSP 3-45 μm Response to Ice

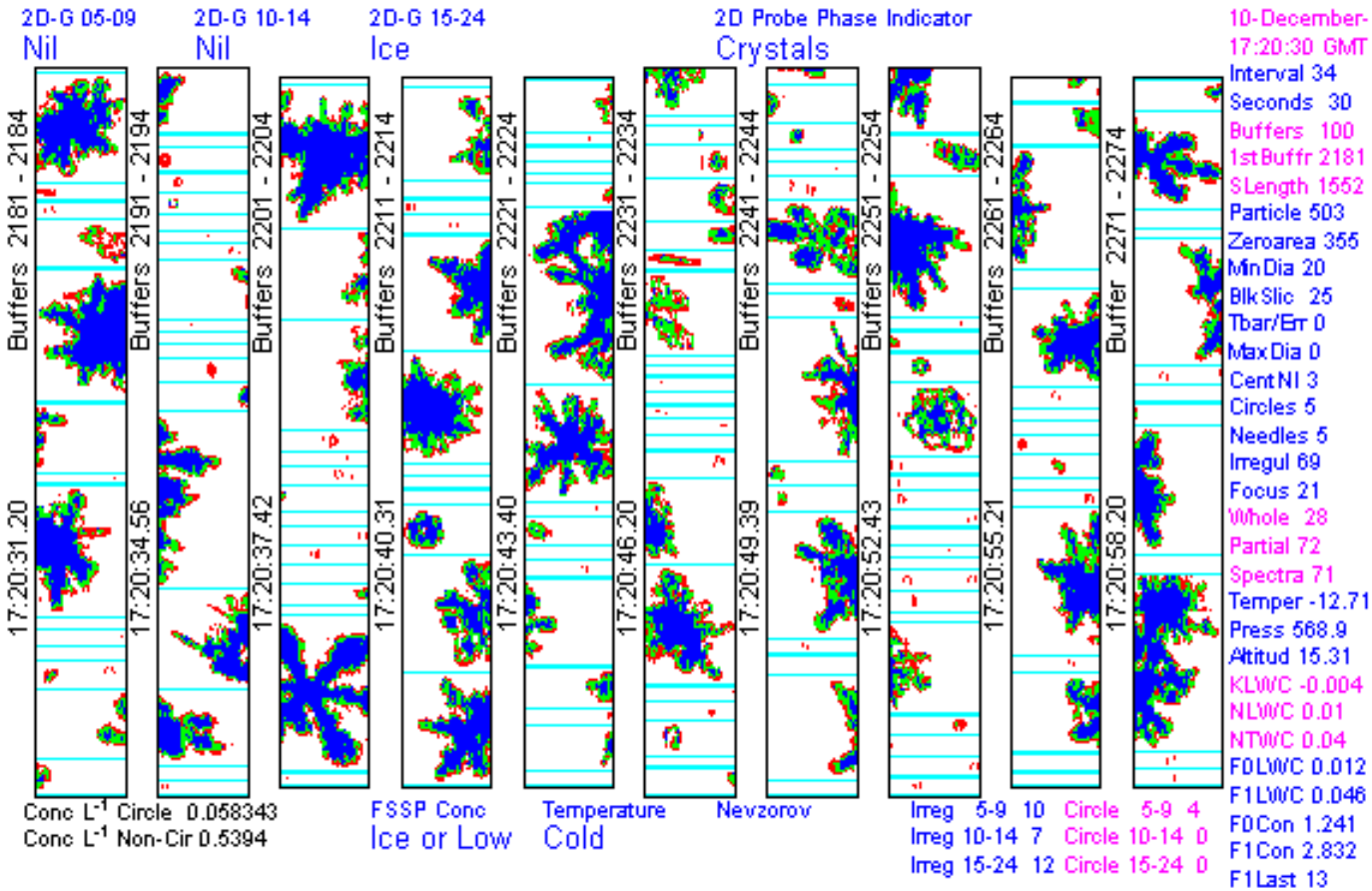


2D Hydrometeor Measurements

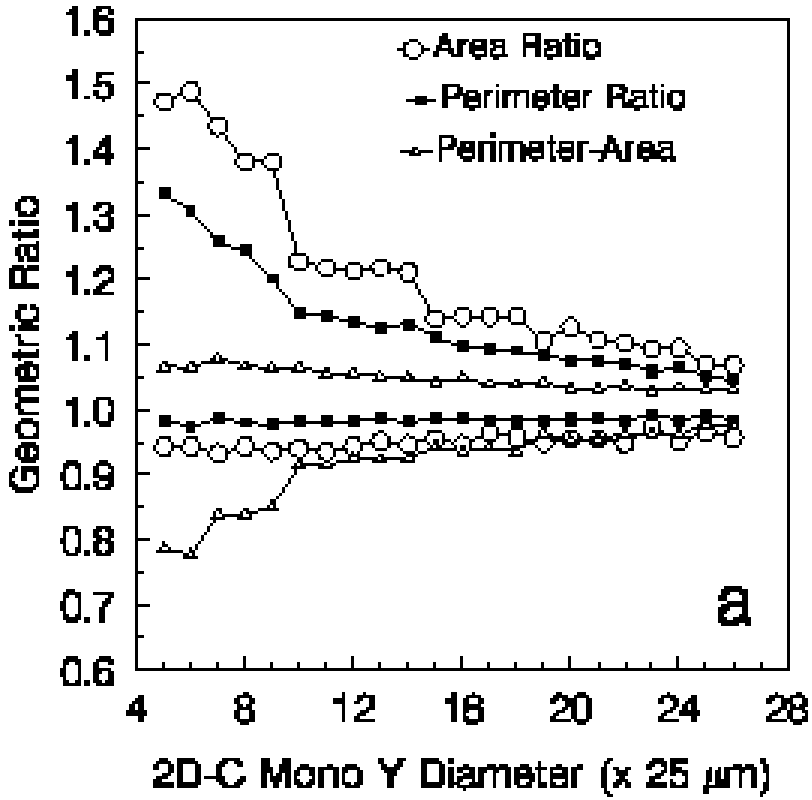
Example of 2D-C Images

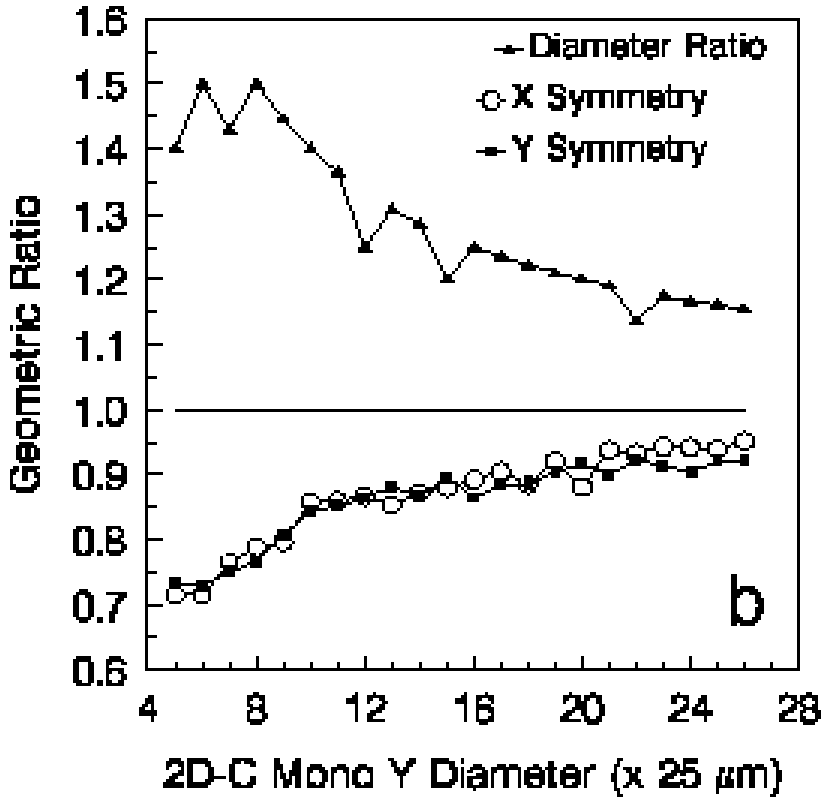


Example of 2D-G Images

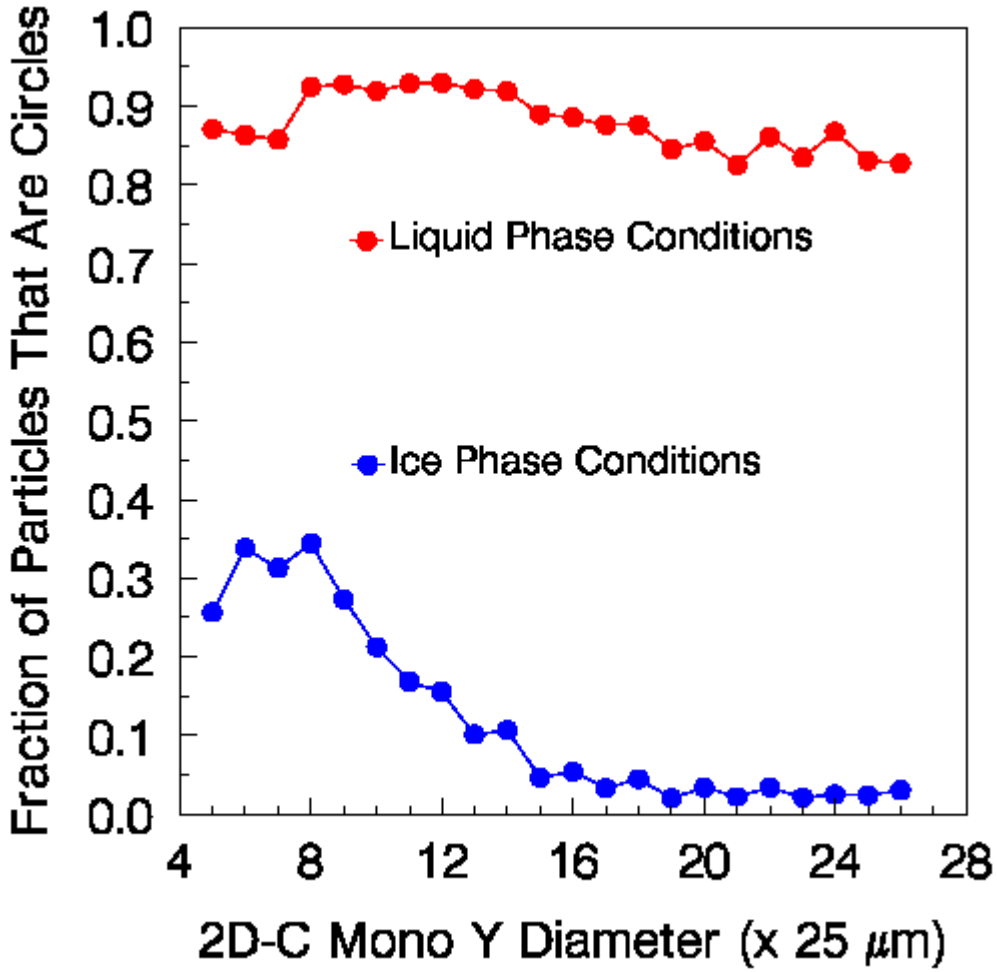


Geometric Ratios for Circles





2D-C Circular Identification Error

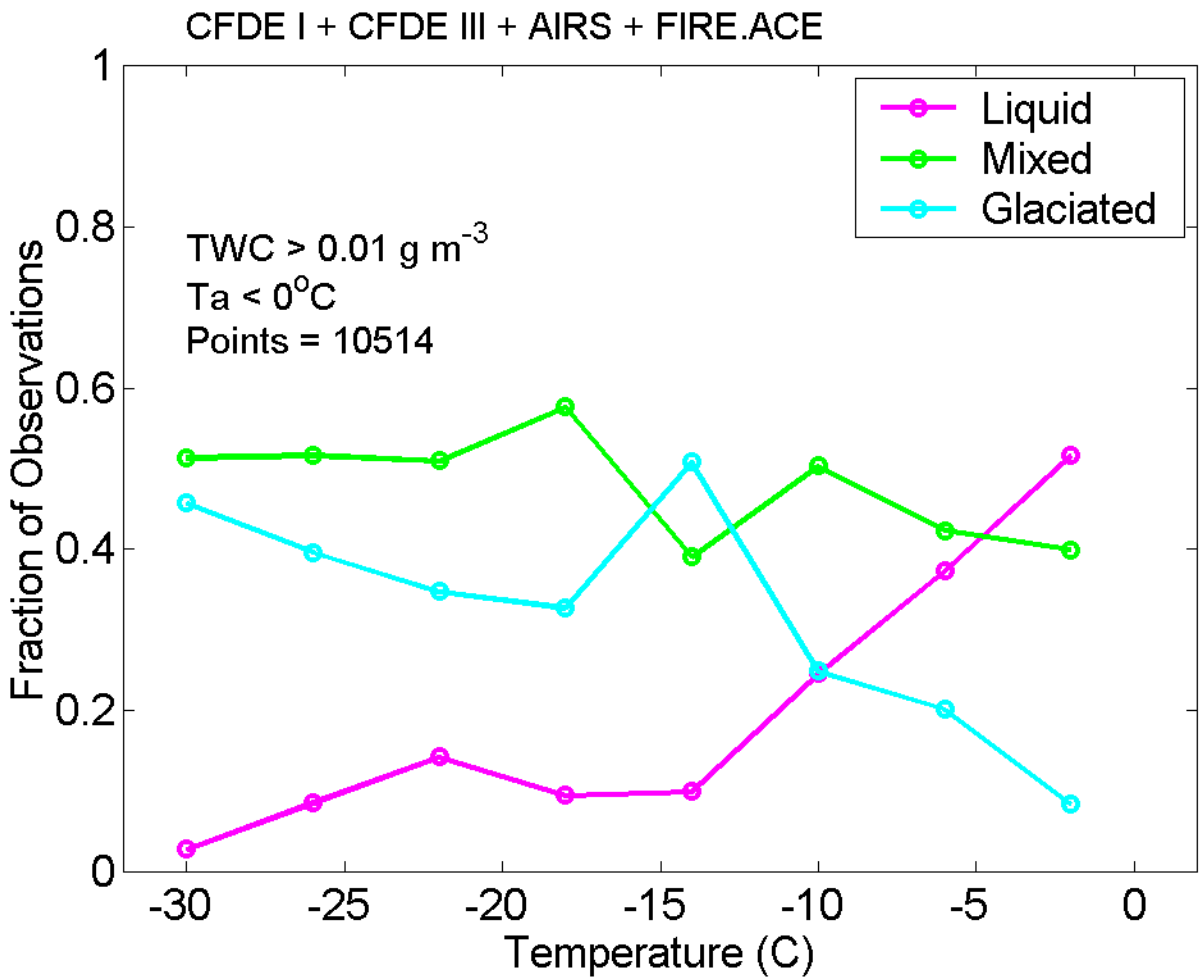


Identification of Cloud Phase

Summary of observed instrument responses for each cloud phase

Parameter	**L**	**G**	**M**	**Notes**
Nevzorov LWC/TWC	> 0.85	< 0.25	0.2-1.0	
King LWC/TWC	> 0.85	< 0.25	0.2-1.0	
2DC Circle Fraction	> 0.85	< 0.35		≥ 5 pixels
2DG Circle Fraction	> 0.85	< 0.40		≥ 5 pixels
FSSP 5-95 50% VD		> 30 μm		99.9% G, 4% L
FSSP 5-95 80% VD		> 40 μm		100% G, 2% L
FSSP Conc		< 15 cm^{-3}		100% G, 8% L
RID Voltage	> 2 mV s^{-1}	< 2 mV s^{-1}	> 2 mV s^{-1}	T < -4°C

Phase Versus Temperature



Conclusions

At approximately 100 m s^{-1}, the following instrument responses need to be considered when characterizing icing conditions:

- Hot wire probes respond to ice crystals (10-20 %)
- FSSP probes are dominated by ice crystals > 35 μm
- 2D probes see drops as non-circles (5-15%)
- 2D probes see crystals as circles (5-40%)
- RID response to icing is non-linear close to 0°C
- The MSC FSSP and 2D instruments cannot be used to assess drop/SLD sizes from 35 to 250 microns when the ice crystal concentration exceeds 1 L^{-1}.

References

Cober, S.G., G.A. Isaac, A.V. Korolev, and J.W. Strapp, 2001: Assessing cloud-phase conditions. *J. Appl. Meteor.*, **40**, 1967-1983.

Korolev, A.V., G.A. Isaac, S.G. Cober, J.W. Strapp, and J. Hallett, 2003: Observations of the microstructure of mixed phase clouds. *Quart. J. Roy. Meteorol. Soc.*, **129**, 39-65.

Cober, S.G., and G.A. Isaac, 2002: Aircraft environments observed in mixed-phase clouds. *AIAA 40th Aerospace Sci. Meeting and Exhibit*, Reno Nevada, 14-17 January 2002, AIAA 2002-0675.

Cober, S.G., G.A. Isaac, and A.V. Korolev, 2001: Assessing the Rosemount icing detector with in-situ measurements. *J. Atmos. Oceanic Technol.*, **18**, 515-528.

Mazin, I.P., Korolev, A.V., A. Heymsfield, G.A. Isaac, and S.G. Cober, 2001: Thermodynamics of icing cylinder for measurements of liquid water content in supercooled clouds. *J. Atmos. Oceanic Technol.*, **18**, 543-558.